

Supplementary Information

Mechanism and kinetics of thermal degradation of insulating materials developed from cellulose fiber and fire retardants

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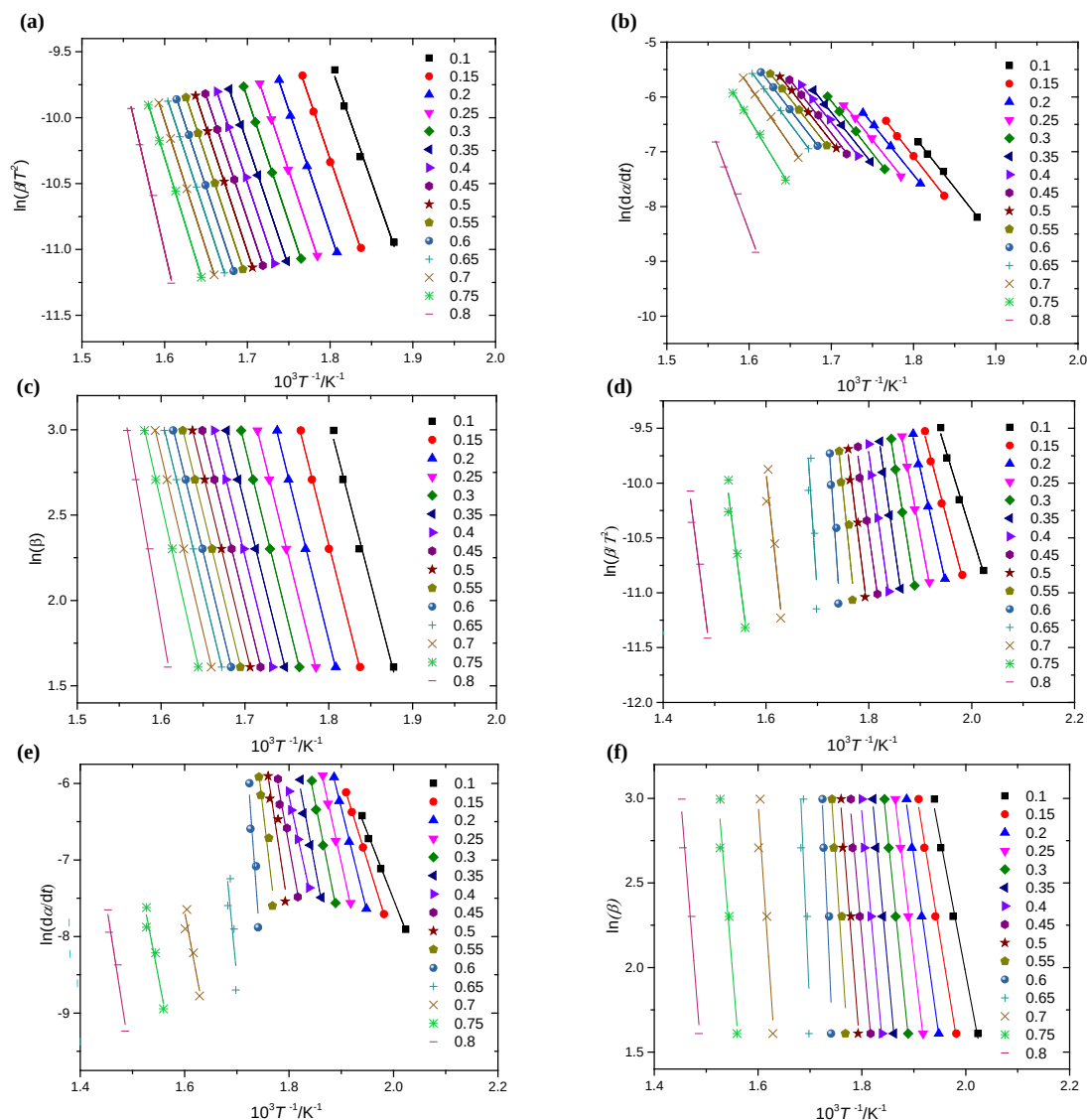
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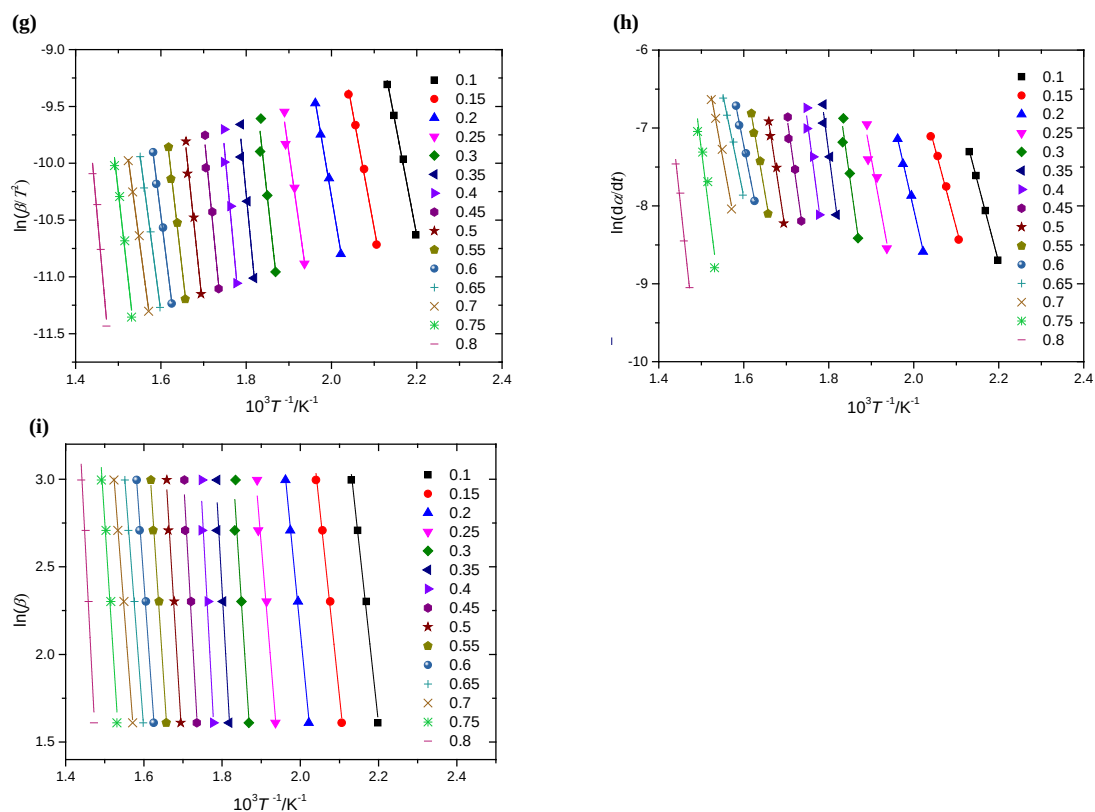


Fig. S1 Linear plots for cellulosic thermal insulating materials obtained by the KAS, Friedman, and FWO methods: **a** Reference KAS; **b** Reference Friedman; **c** Reference FWO; **d** SYIM KAS, **e** SYIM Friedman; **f** SYIM FWO; **g** EGIM KAS; **h** EGIM Friedman; **i** EGIM FWO

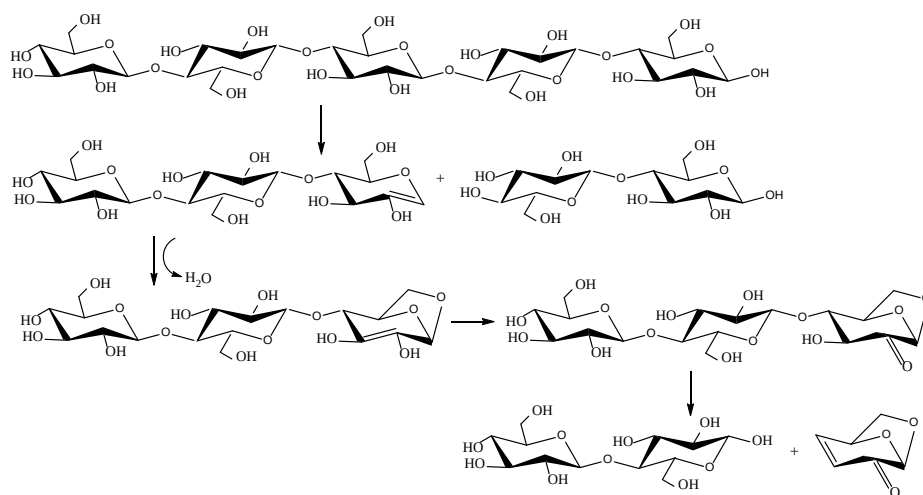


Fig. S2 The formation of levoglucosenone from cellulose (Lu et al., 2014)

Table S1. Algebraic expressions of functions of the most common reaction mechanisms operating in solid-phase reactions (Galwey & Brown, 1999)

Mechanism model	Integral form $g(\alpha)$	Differential form $f(\alpha)$
Nucleation and growth (Avrami equation (1)-A2)	$[-\ln(1 - \alpha)]^{1/2}$	$2(1 - \alpha)[- \ln(1 - \alpha)]^{1/2}$
Nucleation and growth (Avrami equation (2)-A3)	$[-\ln(1 - \alpha)]^{1/3}$	$3(1 - \alpha)[- \ln(1 - \alpha)]^{2/3}$
Nucleation and growth (Avrami equation (3)-A4)	$[-\ln(1 - \alpha)]^{1/4}$	$4(1 - \alpha)[- \ln(1 - \alpha)]^{3/4}$
Phase-boundary-controlled reaction (motion in one dimension)-R1	α	1
Phase-boundary-controlled reaction (contracting area)-R2	$1 - (1 - \alpha)^{1/2}$	$2(1 - \alpha)^{1/2}$
Phase-boundary-controlled reaction (contracting volume)-R3	$1 - (1 - \alpha)^{1/3}$	$3(1 - \alpha)^{2/3}$
Diffusion in one dimension-D1	α^2	$1/(2\alpha)$
Diffusion in two dimensions (Valensi equation)-D2	$(1 - \alpha)\ln(1 - \alpha) + \alpha$	$[- \ln(1 - \alpha)]^{-1}$
Diffusion in three dimensions (Jander equation)-D3	$[1 - (1 - \alpha)^{1/3}]^2$	$3(1 - \alpha)^{2/3}/[2(1 - (1 - \alpha)^{1/3})]$
Random nucleation with one nucleus of individual particle-F1	$-\ln(1 - \alpha)$	$(1 - \alpha)$
Random nucleation with two nuclei of individual particles-F2	$1/(1 - \alpha) - 1$	$(1 - \alpha)^2$
Random nucleation with three nuclei of individual particles-F3	$[1/(1 - \alpha)^2 - 1]/2$	$(1 - \alpha)^3$
Power law-P2	$2 \alpha^{1/2}$	$\alpha^{1/2}$

Table S2. TG and DTG data for the cellulosic thermal insulating materials without and with fire retardants at different heating rates

		Heating rate /°C min ⁻¹	Moisture/%	Volatile/%		Total volatile/%	Residue/%	Onset/°C	Temperature at max. rate			
				Stage I	Stage II				Stage III	Tmax ₁ /°C	Tmax ₂ /°C	Tmax ₃ /°C
Reference	5		4.6±0.3	60.9±3.4	12.2±0.6	78.1±3.9	21.9±3.9	253.5±0.1	320.6±1.2	-	-	
	10		4.3±0.2	59.6±5.4	12.1±1.2	76.4±6.1	23.6±6.1	261.5±0	332.0±0.1	-	-	
	15		4.5±0.8	59.7±1.2	12.7±0.4	75.7±3.3	24.3±3.3	269.6±0	339.3±0	-	-	
	20		4.7±0.5	61.1±2.3	13.4±0.5	79.2±2.6	20.8±2.6	271.5±0.1	344.0±0.9	-	-	
SYIM	5		3.8±0.3	46.4±1.9	15.4±0.6	67.8±2.7	32.2±2.7	220.1±1.4	247.5±1.4	275.2±3.9	-	
	10		3.3±0	43.2±0.5	14.9±0.1	62.6±0.6	37.4±0.6	230.9±0	253.9±1.1	288.1±0.2	-	
	15		3.5±0.1	45.7±2.0	16.2±0.3	66.3±2.2	33.7±2.2	234.3±2.2	258.4±0.9	294.1±1.1	-	
	20		3.4±0.2	45.9±1.8	16.3±0.2	66.5±2.1	33.5±2.1	238.1±0.2	264.4±0.3	295.1±1.0	-	
EGIM	5		6.9±0.4	35.9±1.0	15.7±0.8	64.7±0.6	35.3±0.6	195.7±1.4	198.7±1.0	284.5±0.8	351.0±0.1	
	10		6.5±0	35.6±0	18.0±0.1	65.5±0.2	34.5±0.2	197.3±1.5	209.2±0.1	285.9±0.5	362.3±1.2	
	15		5.9±0.3	34.6±0.2	19.4±0.4	64.4±0.7	35.6±0.7	201.9±0.3	213.6±0.3	290.2±0.2	372.1±0.5	
	20		5.7±0.4	34.9±0.7	20.7±0.3	66.4±0.1	33.6±0.1	199.6±3.0	217.3±2.5	289.0±2.5	374.6±0.2	

Table S3. Activation energy of cellulosic thermal insulating materials calculated by different methods

α	Reference						SYIM						EGIM					
	KAS method		Friedman method		FWO method		KAS method		Friedman method		FWO method		KAS method		Friedman method		FWO method	
	E_a kJ mol ⁻¹	R^2	E_a kJ mol ⁻¹	R^2	E_a kJ mol ⁻¹	R^2	E_a kJ mol ⁻¹	R^2	E_a kJ mol ⁻¹	R^2	E_a kJ mol ⁻¹	R^2	E_a kJ mol ⁻¹	R^2	E_a kJ mol ⁻¹	R^2	E_a kJ mol ⁻¹	R^2
0.1	149	0.98878	159	0.9972	150	0.98995	126	0.98813	144	0.99481	128	0.98947	163	0.99145	172	0.99901	162	0.99224
0.15	153	0.99846	159	0.9995	154	0.9986	148	0.99129	182	0.9997	148	0.9921	169	0.99295	169	0.98941	168	0.99361
0.2	155	0.99936	154	0.99916	156	0.99941	174	0.99581	229	0.9987	174	0.9961	183	0.99634	199	0.99624	182	0.99667
0.25	156	0.99978	156	0.99825	157	0.9998	207	0.99768	258	0.9954	205	0.9978	219	0.96137	247	0.88414	216	0.96421
0.3	156	0.99997	159	0.99931	158	0.99997	242	0.99753	286	0.9912	239	0.9976	281	0.90729	322	0.91322	276	0.91262
0.35	156	0.99987	156	0.99975	157	0.99988	272	0.99308	303	0.9644	267	0.9935	323	0.93473	346	0.95538	316	0.93816
0.4	156	0.99973	155	0.99934	158	0.99976	278	0.98596	262	0.9896	273	0.9868	338	0.92577	343	0.92484	330	0.92958
0.45	156	0.99993	161	0.99834	158	0.99995	278	0.97645	315	0.9646	273	0.9779	323	0.95589	321	0.959	316	0.95836
0.5	158	0.99995	158	0.99942	159	0.99996	315	0.95844	373	0.8681	309	0.9607	297	0.97702	296	0.9844	291	0.97846
0.55	157	0.99976	158	0.9999	159	0.9998	379	0.88028	484	0.8858	370	0.8856	272	0.98916	263	0.98818	269	0.98993
0.6	157	0.99969	162	0.9997	159	0.99974	576	0.83962	776	0.8442	557	0.8443	249	0.99211	229	0.99344	247	0.99273
0.65	159	0.99987	167	0.99962	161	0.9999	588	0.54953	587	0.4634	568	0.5599	234	0.99738	221	0.98947	232	0.99762
0.7	162	0.99978	180	0.99916	164	0.99982	364	0.83716	301	0.8289	355	0.8451	231	0.99678	246	0.98748	229	0.99708
0.75	169	0.99938	206	0.99651	171	0.99946	299	0.91795	294	0.9094	295	0.9233	278	0.97351	360	0.89767	274	0.97552
0.8	224	0.99429	337	0.98497	223	0.99481	304	0.94524	361	0.9384	300	0.9489	350	0.96237	421	0.9712	344	0.9647
Mean±SD	162±18		175±47		163±17		303±139		343±168		297±133		261±61		277±74		257±58	